Appendix C

Bull Run Groundwater-based Alternative Technical Memorandum

Bull Run Groundwater-Based Alternative

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Introduction

This technical memo has been prepared to respond to a suggestion in a July 11, 2006 letter from the Portland Utility Review Board (the Board). The Board suggested that an alternative be analyzed that utilizes groundwater to supplement reservoir water to meet flow and temperature requirements in the Bull Run River below Dam No. 2. The specific request from the Board was as follows:

"Augment Bull Run Reservoir water with groundwater from one or more of the existing well fields already established at Headworks. Use of cool groundwater "stretches" the cool reservoir water reserve, allowing it to enter the Bull Run River at a slower pace combined with artesian water, downstream of Headworks."

The Board indicated that this groundwater augmentation would obviate the need for additional releases from the Bull Run reservoirs and for the proposed multi-tier intake at Dam No. 2 to reduce water temperatures in the lower Bull Run River per Measure T-2 of the Bull Run HCP. The Board also recommended prohibiting the addition of gravel and logs into the river inside the Bull Run Management Unit and requiring streamside tree planting along the Little Sandy River.

At the City's request, CH2M HILL analyzed this alternative using the following parameters:

- Assume the use of the existing wells already established at Headworks plus wells that have not been built but were recommended by Bureau staff in the mid-1990s, a total of 8 wells (this is not literally what the Board requested, but seemed like a reasonable interpretation of its request).
- Assume that the alternative must meet the same temperature and flow requirements as the proposed action in the HCP for the summer period. (The Board does not mention flow, but this seemed like a reasonable interpretation of its request. The Board also did not specifically mention the period during which the groundwater would be used, but it seemed a reasonable interpretation to analyze the summer period when the most critical temperature and water supply issues exist).

- Do not analyze the effects of not placing gravel or large wood in the river or tree planting along the Little Sandy River as these do not directly affect the flow or temperature issues.

- Assume that the City would not “mine” the groundwater unsustainably and, therefore, that the City would withdraw only what was determined to be a sustainable withdrawal rate.

To accomplish this analysis, CH2M HILL reviewed previous studies of the hydrogeology in the Headworks area, then developed and evaluated a conceptual alternative to augment Bull Run River flows with groundwater. Groundwater is used instead of reservoir water to attempt to implement the temperature Measure T-2 described in the proposed Bull Run HCP.

This analysis is documented in this report, which includes the following sections:

- A description of groundwater character and supply in the Headworks area
- A description of the specific objectives of a groundwater alternative
- Analysis of the components or features of a groundwater alternative
- Conclusions and final considerations

Groundwater Character and Supply in the Headworks Area

History of Previous Groundwater Development Activities

A history of previous hydrogeologic studies and well testing activities in the Headworks area was presented by Murray, Smith & Associates (MSA 2005). From 1998 through 2004, the City conducted a phased program of exploratory well drilling and testing to develop an understanding of the depths, potential yields, and water quality of groundwater-bearing zones in the Headworks area. These studies (Squier Associates 1999; Geller 2001; Golder 2003; and Golder 2004) found that groundwater is present in deep basalt aquifers, and that a groundwater supply with a capacity of up to 20 million gallons per day (mgd) - equivalent to roughly 30 cfs – could potentially be developed in this area.

The studies performed by the City followed the publication of a report by the U.S. Geological Survey suggesting the possibility of developing a groundwater supply in the Bull Run watershed. Upon completion of the studies, the City began a program to develop conceptual and preliminary engineering designs for development of a groundwater production system with an initial capacity of either 10 mgd or 20 mgd (roughly 15 to 30 cfs). The City identified several potential uses of the groundwater supply system, including:

- Providing a backup or emergency supply source.

- Providing for operational flexibility of the Bull Run conduits during high turbidity events in the Bull Run surface water source (turbidity at or near 5 nephelometric turbidity units [NTUs]). This operational flexibility could occur as either blending of the groundwater supply with Bull Run surface water or using groundwater as a sole source of water to put into the water supply conduits.

- Providing additional supply during seasonal peak demand periods.

Bureau staff projected development of the groundwater source in two phases. Phase 1 was designed to consist of four wells providing approximately 10 mgd of groundwater supply capacity. Phase 2 was designed to consist of four additional wells providing an additional approximately 10 mgd of groundwater supply capacity for a total of approximately 20 mgd of groundwater from eight wells.

The potential to implement aquifer storage and recovery (ASR) capability as part of the project was also considered. ASR is a process that injects clean water into an aquifer through a groundwater well, creating a mound or zone of increased water level around the well and displacing native groundwater. The injected water is later recovered from the well through pumping when it is needed. The process is most commonly applied in confined aquifers where water removal reduces the piezometric surface (or confining pressure) of the aquifer and water injection causes the piezometric surface (confining pressure) to increase. MSA (2005) identified ASR as a potential water management strategy for the Headworks wellfield because the Winter Water/Ortley aquifer is confined and the Bull Run watershed produces an abundance of water during the winter months, which could be stored at that time and then pumped for use during the summer.

As discussed by MSA (2005), peer reviewers for the preliminary design program concluded that ASR could be beneficial because (1) the native groundwater supply might eventually become depleted, and (2) the lower silicon and fluoride concentrations in the injected and recovered Bull Run surface water would be preferred for municipal and industrial (M&I) use compared to the native groundwater that is present in the Headworks area.

The peer reviewers also recommended that the ASR system include a membrane filtration (MF) plant to treat the Bull Run surface water prior to injection (at a rate of approximately 10 mgd) to minimize the potential for aquifer plugging problems. The peer reviewers noted that the MF plant's 10 mgd capacity raises the capacity of the entire system from 20 mgd to 30 mgd for non-peak high-turbidity reservoir shutdown periods.

As discussed by MSA (2005), during the summer of 2004, the City decided to suspend further planning and design of the groundwater system in the Bull Run watershed. The factors leading to this decision included the results of the preliminary design study and other issues of broader, system-wide significance. Specifically:

The preliminary design study identified potential operating constraints posed by the presence of natural levels of silica and fluoride in the groundwater, which were concluded to limit the ability of the City to use the groundwater for one of its primary intended purposes – providing Headworks groundwater for M&I use to replace the Bull Run source during high turbidity periods (as a means to keep one or more of the water supply conduits operational).

- MSA (2005) and the City concluded there were uncertainties with respect to water supply decisions that would ultimately bear on the development of a water supply project at Headworks for M&I uses. These included availability of Bull Run groundwater rights, potential instream flow requirements for fish habitat needs if a new water source were to be developed in the watershed, the available capacity of and demand for water from the existing Columbia South Shore Wellfield, and the pending Bull Run surface water treatment decision. The City concluded that these issues would continue to greatly influence the value of Bull Run groundwater as a future component of the City's system for providing water supplies intended for M&I uses.

Description of Headworks Well Field and Aquifer System

The understanding of the aquifer system in the Headworks area was developed by the City through the phased exploratory well drilling and testing program conducted from 1998 through 2004. During this program, the City installed one piezometer well, five test (pilot) wells, and one larger test-production well. Figure 1 shows the well locations. These wells were installed to depths of between 650 and 750 feet and obtained groundwater from the Winter Water and Ortley units of the Columbia River Basalt Group. Results of aquifer testing in the Headworks vicinity indicated that the Winter Water/Ortley piezometric surface is above ground surface, as artesian conditions exist in all but one well (Pilot Well No. 2, located adjacent to the spillway approach channel).

Other significant findings of the phased exploratory program were summarized by Golder (2004) and are as follows:

1. The transmissivity of the Winter Water/Ortley aquifer system ranges from 80,000 to 100,000 gallons per day per ft (gpd/ft) in the Headworks area, and may be as high as 180,000 to 200,000 gpd/ft in more distant areas farther from Headworks. The storativity of the aquifer is estimated to be on the order of 1×10^{-4} to 2×10^{-4}. The aquifer is highly confined, as indicated by the flowing wells at all but one location. The exploratory program concluded that the aquifer is capable of yielding several thousand gallons per minute (gpm) to wells with little short-term drawdown.
2. The Headworks wellfield area is located within, and near the axis of, the Bull Run Syncline, a structural fold that is thought to be associated with the Yakima Fold Belt. The aquifer is thought to be extensive, lying perhaps as far as 20 miles from the Headworks (in the direction parallel with the axis of the syncline). The exploratory program projected that steeply-dipping, northwest-trending strike-slip faults are present in the Headworks area. While the aquifer testing work in the wellfield identified the presence of low-permeability boundaries, the program did not attribute these boundaries to any specific geologic features.
3. While the exploratory program concluded that the aquifer is areally extensive along the axis of the Bull Run Syncline and also highly transmissive, the program also concluded that the aquifer system is recharge-limited. This finding was based on the partial (rather than complete) recovery of water levels that was observed after the pumping phases of the various aquifer tests that were conducted for the exploratory program. Golder (2004) concluded that long-term use of the aquifer could result in permanent declines in the piezometric surface within the aquifer system, unless leakages from the reservoirs or the aquifer boundaries were to be induced on a long-term basis by the lowering of the piezometric surface. Without appreciable leakage, a decrease in the piezometric surface is anticipated to occur over time as water is removed from the aquifer. Golder (2004) concluded that the amount of non-recoverable drawdown for any groundwater supply system that is operated on a long-term basis would depend on the pumping rate, the pumping duration, and the amount of recharge induced by the pumping activity. Golder (2004) also stated that long-term operational pumping would be required to

obtain an estimate of the long-term leakage rates to the aquifer. Golder (2004) recommended that the ability to implement ASR be built into the designs of any new production wells to be installed in the Headworks area, given that the ability to inject and recover water would help mitigate any long-term decline in groundwater levels that might otherwise occur.

4. The exploratory program also found that the Winter Water/Ortley aquifer system is overlain by a thick deposit of very dense, relatively unfractured basalt that comprises the lower unit of the Sentinel Bluffs unit (also known as Sentinel Bluffs II). This unit in turn is overlain by landslide and terrace deposits. Analyses of groundwater piezometric data and water surface elevation data from Bull Run Reservoir No. 2 indicate that the bulk vertical hydraulic conductivity of the Sentinel Bluffs and overlying units is very low (on the order of 2.7×10^{-9} centimeters per second) and that these units act as a confining unit (aquitard). This finding indicates that water exchanges between the reservoir and the Winter Water/Ortley aquifer system are very small, and that the reservoir is not a significant source of recharge to the underlying aquifer system. The observed lithology above the aquifer system, along with the groundwater piezometric data and the reservoir elevation data, also indicate that little discharge occurs from the aquifer to the reservoir or from the aquifer to the Bull Run River in the area downstream of Headworks.

Groundwater Flows

Pumping tests were conducted during the City's phased exploratory groundwater program to assess yield of groundwater from wells in the Headworks area (MSA 2005). Multi-day artesian flow tests (with no pumping) were conducted ranging from several days to as long as four weeks, plus occasional constant-rate aquifer pumping tests of shorter duration (typically 72 hours). The results of these tests indicated that a groundwater yield of about 20 mgd (31 cfs) could be achieved from the Headworks wellfield design being considered for development by the City (MSA 2005). The wellfield design consisted of an eastern and western wellfield containing wells pumping at rates of between 1,000 gpm and 3,000 gpm per well, which is equivalent to a range of 2.23 cfs (or 1.44 mgd) to 6.69 cfs (or 4.32 mgd).

The wellfield layout in the Headworks area is shown in Figure 1. As shown in the figure, the wells that would be operated for the 20 mgd pumping rate are existing well PW-1 and new wells PW-2 through PW-8, which would each draw from the same water-bearing zone (the Winter Water/Ortley aquifer system). Longer-term sustained pumping tests have not occurred from the existing test wells in the Headworks area. Consequently, the long-term effects on groundwater yield of sustained pumping at a 20 mgd rate are uncertain at this time. However, water level monitoring that was performed during the exploratory program showed only partial recovery of groundwater piezometric heads in the aquifer several days after the flow tests or constant-rate pumping tests had ended. The final report for the phased exploratory program (Golder 2004) concluded that these data indicate the possibility that long-term continual use of the aquifer could result in a permanent decline in the piezometric surface, unless significant recharge is induced by the lowering of the piezometric surface.

Groundwater Temperature and Quality

Water temperatures of groundwater in the Headworks area have been measured at various times over almost 10 years. Temperature was measured during each phase of the exploratory program (See Table 1, compiled by Golder, 2004). Groundwater temperatures ranged from 10.3°C to 17.1°C and averaged 14.8°C. Tests in March 1999 (at the first test well), May/June 2001 (flow test #2 at test well PW-1), and February 2004 (at Pilot Well #3) showed that temperature fluctuations were minimal (less than 1°C) during each test, though the 1999 test showed an increase of 0.7°C over a 3-day period. More recently, in March 2007, the City measured groundwater temperatures of 13.1 to 14.2°C in monitoring wells in the Headworks area (S. Kucas, City of Portland, pers. comm.). These included the wells labeled "Pilot 1", "Pilot 3", and "PW-1" on Figure 1.

TABLE 1
Summary of Groundwater Temperature Data from Pilot Well Testing, Bull Run Groundwater Supply Investigations

Measurement Date	Temperature (°C)	Location	Reference
11/19/1998	13.1	Piezometer	Squier Associates (June 1999), Table 3
3/15/1999	16.0	Test Well	
3/18/1999	16.7	Test Well	
4/15/1999	11.9	Piezometer	
5/16/2001	15.0	PW-1 (Pump Test)	Portland Bureau of Water Works (2001), Appendix A
5/17/2001	15.0	PW-1 (Pump Test)	
5/25/2001	15.2	PW-1 (Flow Test #2)	
5/29/2001	15.1	PW-1 (Flow Test #2)	
5/31/2001	15.3	PW-1 (Flow Test #2)	
6/5/2001	15.0	PW-1 (Flow Test #2)	
6/7/2001	15.4	PW-1 (Flow Test #2)	
6/12/2001	15.0	PW-1 (Flow Test #2)	
2/7/2003	16.1	Pilot Well #1	Golder Associates (July 2003), Appendix E
3/10/2003	17.1	Pilot Well #2	
2/2/2004	15.7	Pilot Well #3	Golder Associates (July 2004), Appendix E
2/11/2004	15.9	Pilot Well #3	
2/11/2004	12.6	Pilot Well #4	
1/12/2004	10.3	Bear Creek	

Other water quality data were collected during each pumping test as summarized by Golder (2004). Silicon concentrations in the Winter Water/Ortley aquifer system were found to be elevated (on the order of 50 to 70 milligrams per liter [mg/L]) compared with Bull Run reservoir surface water (4 to 5 mg/L). However, there are no water quality standards for it and silicon levels of this magnitude are not known to harm aquatic productivity or fish. The water quality testing work also included metals and nutrients, constituents to which surface water quality and fish productivity are potentially sensitive. These data are summarized in Table 2. As shown in the table, metals were detected infrequently and at concentrations that are well below criteria for acute or chronic effects on fish (based on criteria in EPA 2006). The nutrients nitrate and ammonia were below detection in all analyzed samples. However, phosphate was detected in concentrations of 0.02 to 0.05 mg/L in analyzed samples. Although these phosphate concentrations are ample to supply growth of algae, they are generally below concentrations of 0.05 to 0.10 mg/L considered indicative of nutrient enrichment conditions in rivers and streams (Welch 1992, EPA 2000).

Groundwater and Fish Homing

The groundwater alternative must consider the potential impact on salmonid spawning from mixing groundwater with native Bull Run Water. This occurs because there is the possibility of an impact to homing salmon caused by augmentation of groundwater to the lower Bull Run River. Research indicates that salmon learn the chemical characteristics of their natal stream during rearing and out migration through olfactory “imprinting”, remember the imprinted chemical cues during ocean residence, and respond to these cues as returning adults (Dittman and Quinn 1996). The specific chemical substances or attributes that determine a salmon’s imprinting and homing cues are not well defined and are known to be very complex. However, the particular chemical characteristics or signature of a river provide important homing cues that could be altered by significant discharge of groundwater to the river.

Objectives for a Groundwater-Based Alternative

The primary objective of a groundwater-based alternative is to provide groundwater augmentation to the Bull Run River below the Headworks during the summer months to help reduce water temperatures in the river so as to achieve temperature targets at Larson’s Bridge in accordance with the proposed Bull Run HCP Measure T-2. Although not specifically identified by the Board, the groundwater augmentation quantities would need to be sufficient that, when added to available surface flows, the minimum instream flow objectives for the lower Bull Run River would also be achieved (per Bull Run HCP Measures F-1 and F-2).

Bull Run HCP Measure T-2 calls for the City to manage water temperatures in the lower Bull Run River to meet Oregon state water quality standards, as established in ODEQ’s Sandy River Basin TMDL. The City would use the Little Sandy River temperature (measured at USGS gauge 14141500) as a surrogate for the natural thermal potential of the lower Bull Run River. Compliance would be measured at Larson’s Bridge on the mainstem Bull Run River (USGS site 14140020), which is located at RM 3.8, about two miles downstream of Headworks where the City’s flow releases to the river are made. Under Measure T-2, water temperature at Larson’s Bridge would be maintained at or below the appropriate state water quality numeric criteria (i.e., 16°C during salmonid juvenile rearing and 13°C during salmonid spawning, egg incubation, and fry emergence) when the Little Sandy River temperature is below the criteria, or at or below the Little Sandy River

TABLE 2
Summary of Metals and Nutrients in Bull Run Groundwater (from Pilot Well Testing). Metals include Cadmium (Cd), Copper (Cu), Iron (Fe), Lead (Pb), Mercury (Hg), and Zinc (Zn). Nutrients include Phosphate (PO4), Nitrate (NO3), and Ammonia (NH4).

Sample Date	Cd	Cu	Fe	Pb	Hg	Zn	PO4	NO3	NH4	Location	Source
11/19/1998	NA[a]	NA	0.07[c]	NA	NA	NA	NA	NA	NA	Piezometer	Squier 1999; Golder 2003
3/15/1999	BD[b]	BD	0.058[c]	0.041	BD	0.014	0.02[d]	BD	NA	Test Well	Squier 1999; Golder 2003
3/18/1999	BD	BD	BD	.0009	BD	BD	0.02[d]	BD	NA	Test Well	Squier 1999; Golder 2003
4/15/1999	BD	BD	0.068[c]	.0007	BD	0.011	0.05[d]	BD	NA	Piezometer	Squier 1999; Golder 2003
5/4/2001	NA	BD	BD	NA	NA	BD	NA	NA	BD	Sample ID Bull Run - 1	Geller 2001; Golder 2003
5/16/2001	BD	BD	BD	BD	BD	BD	0.032[e]	BD	BD	Sample ID Bull Run - 2	Geller 2001; Golder 2003
2/7/2003	BD	BD	BD	BD	BD	BD	NA	BD	NA	Pilot Well #1	Golder 2003
3/10/2003	BD	0.01	BD	0.001	BD	BD	NA	BD	NA	Pilot Well #2	Golder 2003
2/2/2004	NA	NA	BD	NA	NA	.0097	NA	BD	BD	Pilot Well #3	Golder 2004
2/11/2004	NA	NA	0.015[c]	NA	NA	BD	NA	BD	BD	Pilot Well #3	Golder 2004
2/11/2004	BD	BD	BD	BD	BD	BD	NA	BD	NA	Pilot Well #4	Golder 2004

a: NA = sample not analyzed for this parameter
b: BD = sample analysis was below detection limit for this parameter
c: value is for total iron (Fe); dissolved iron was BD or NA for these samples
d: value is for total phosphate (PO4)
e: value is for soluble orthophosphate

temperature (or as otherwise adjusted[1]) when the Little Sandy River temperatures are above the numeric criteria.

The proposed Bull Run HCP specifies that the instream flow regime in the lower Bull Run River would be structured according to four key components: (1) a guaranteed minimum flow, (2) variable flow to manage temperature, (3) a fall season flow increment based on percent of reservoir inflow, and (4) a maximum required flow (cap) to manage reservoir refill. The variable flow component to manage temperature would be implemented in summer (July through September), when the reservoirs would be operated to take advantage of the limited amount of cold water that can be stored. During mild weather, when temperatures in the river are naturally lower, less cold water would be released from the reservoirs. During warm weather, when cold water from the reservoirs is needed to moderate river temperatures, more cold water would be released. The resulting instream flow releases in the lower Bull Run River would vary from 20 to 40 cubic feet per second (cfs) and average about 35 cfs during the summer period.

For purposes of this Technical Memorandum, we set the temperature and instream flow objectives during the summer period as follows:

1. Meet a temperature target of 16°C (or the corresponding Little Sandy River temperature when the Little Sandy River temperatures are above 16°C) in the lower Bull Run River at Larson's Bridge during summer
2. Meet a target instream flow of 20 to 40 cfs in the lower Bull Run River during summer

Analysis of a Groundwater Alternative

Groundwater Temperature and Flow Necessary to Meet River Temperature Objectives

The temperature and flow volume of groundwater that would be needed to meet temperature targets in the lower Bull Run River at Larson's Bridge during summer depend on several factors or conditions that provide the characteristic thermal conditions in the lower Bull Run River. Key factors important to the study and analysis of temperature dynamics in rivers and streams include solar radiation (and associated streamside shading), air temperature, river flow volume and depth, and the upstream boundary or "starting" temperature of water flowing into the river reach of interest (Poole et al. 2001).

The City has created a regression model for the lower Bull Run River to predict the maximum daily temperature of the river at Larson's Bridge when the Dam 2 release temperatures are known (Leighton and Kucas 2004). For purposes of this analysis, it is assumed that the Dam 2 release temperatures represent "starting" temperatures of water flowing into the lower Bull Run River from Headworks. Inputs into the City's regression model include the amount and temperature of water released from Dam 2, the ambient maximum air temperature, and the maximum daily sun angle. The City created and validated the regression model from empirical data collected for the lower Bull Run River. The model's regression coefficient (r^2 value) is 0.89 which means the model's outputs are

[1] Under ODEQ rules, adjustments set the Bull Run standard 1.0° C above the actual measured Little Sandy temperature from August 16th to October 15th.

highly correlated with what is actually measured on the river (see Leighton and Kucas 2004 for more information on the regression model).

A key conclusion from the City's regression model is that the temperature of the water released from Dam 2 to the lower Bull Run River must be between 8°C and 12°C—depending on the values of some of the independent variables—to meet the temperature targets at Larson's Bridge. The groundwater temperature information presented previously indicates a reasonable average steady-state temperature of approximately 13°C to 14°C. Based on this information, Leighton and Kucas (2004) concluded that the groundwater for release into the lower Bull Run River is too warm to create downstream temperatures that would be in compliance with the state temperature criteria.

For this technical memorandum, we independently assessed groundwater temperature and flow requirements based on calculations using example empirical data for three recent summer seasons (2000, 2001, and 2003). The data and resultant calculated values are tabulated in Attachment 1.

The key empirical data used in our assessment include:

- Daily water temperature (°C) from Reservoir 2 (Dam 2 release temperatures represent "starting" temperatures of water flowing into the lower Bull Run River from Headworks).
- Daily maximum water temperature (°C) at Larson's Bridge (this temperature represents the point of compliance for Bull Run HCP Measure T-2).
- Daily flow (cfs) in the lower Bull Run River.
- Daily maximum water temperature (°C) in the Little Sandy River (this temperature represents the target temperature to be achieved at Larson's Bridge when temperature in the Little Sandy River exceeds the numeric target during summer of 16°C).

The key calculations performed in our assessment include:

- Estimated change in daily maximum water temperature from Headworks to Larson's Bridge (obtained by subtracting the Dam 2 release temperature from the temperature at Larson's Bridge).
- Estimated daily maximum water temperature target at Larson's Bridge (this was set at 16°C when Little Sandy River temperatures were at or below 16°C, or equal to the Little Sandy River temperatures when they were above 16°C, or as otherwise adjusted[2]).
- Estimated "starting" temperatures of water flowing into the lower Bull Run River from Headworks that would be needed to match the temperature target at Larson's Bridge (this was estimated by subtracting the estimated change in temperature from Headworks to Larson's Bridge from the estimated temperature target at Larson's Bridge).

[2] Under ODEQ rules, adjustments set the Bull Run standard 1.0° C above the actual measured Little Sandy temperature from August 16th to October 15th.

- Estimated amount of groundwater flow that would be needed to augment the lower Bull Run River to achieve the temperature target at Larson's Bridge. Simple mass-balance calculations were made to estimate the amount of groundwater augmentation flow (in cfs) needed to achieve the target temperature. The mass balance equation used was of the form:

  $(Q_{HW} \times T_{HW}) + (Q_{GW} \times T_{GW}) = (Q_{BRR} \times T_{BRR})$, where:

  Q_{HW} = assumed Headworks release flow (cfs)

  T_{HW} = assumed Headworks release temperature (°C)

  Q_{GW} = assumed groundwater augmentation flow (cfs)

  T_{GW} = assumed groundwater temperature (°C)

  Q_{BRR} = target lower Bull Run River flow (cfs)

  T_{BRR} = target lower Bull Run River temperature (°C)

Calculations were performed in a spreadsheet for each day represented in the example empirical data for the summers of 2000, 2001, and 2003. The above formula was rearranged to solve for assumed groundwater augmentation flow (Q_{GW}). In the formula, the Headworks release temperature (T_{HW}) is assumed to be the estimated "starting" temperature of the river at Headworks that would be needed to match the temperature target at Larson's Bridge (T_{BRR}). The daily empirical flow values (cfs) in the lower Bull Run River were assumed to represent the target lower Bull Run River flows (Q_{BRR}). This was considered a reasonable assumption since the flows that occurred on the example dates are within the minimum instream flow ranges specified in Bull Run HCP Measures F-1 and F-2. The calculations were performed using two assumed groundwater temperatures (T_{GW}), 13°C and 14°C, which reasonably bracket the approximate average temperature of groundwater in the Headworks area.

It should be noted that a mass balance equation of the form used here assumes that water temperatures and flows are "conservative" substances. A conservative substance is one that does not undergo any transformation or degradation as it moves through the ecosystem. Flow, for example, can reasonably be assumed to be a conservative substance in these mass balance calculations because there is minor, if any, change in flow quantity between Headworks and Larson's Bridge, particularly during summer. Conversely, water temperature is not a conservative substance because warming typically occurs between Headworks and Larson's Bridge during summer. A mass balance equation provides an accurate approximation of water temperature conditions at the "starting temperature" point (Headworks), since the discharge and mixing of augmented groundwater at this point would occur much more rapidly than potential warming due to ambient meteorological conditions. However, downstream at Larson's Bridge, the mass balance equation does not specifically calculate the increment of downstream warming that occurs between Headworks and Larson's Bridge during summer. We accommodated this issue by using the regression calculations (determined from actual empirical data for the river) that account for this change in temperature by subtracting these changes from the "starting temperatures" at Headworks that are used in the mass balance equation. Therefore, downstream warming increments are built in to the Headworks "starting temperatures" used in the calculations.

Results of the calculations (as tabulated in Attachment 1) are summarized in Tables 3 and 4 for the various conditions represented by the empirical data. Table 3 summarizes the following: (1) actual maximum daily water temperature at Headworks; (2) the actual change in maximum daily water temperature from Headworks to Larson's Bridge; and (3) the calculated "starting" temperature that would be needed at Headworks to achieve temperature targets at Larson's Bridge (per Bull Run HCP Measure T-2). The calculated starting temperatures at Headworks range from 8.2°C to 17.0°C, with a mean of about 12°C to 13°C. The minimum-to-mean spread within this range supports the previous conclusion by Leighton and Kucas (2004) (using the City's regression model) that the temperature of the water released from Dam 2 to the lower Bull Run River must be between about 8°C and 12°C to meet the temperature targets at Larson's Bridge. The higher end of the range we calculated (up to 17.0°C) arises primarily because the temperature targets at Larson's Bridge are not consistently 16°C or less (as assumed by Leighton and Kucas 2004), but are as high as 20°C on occasion based on Little Sandy River surrogate temperatures. Since the groundwater temperatures average between 13°C and 14°C, groundwater cannot meet temperature requirements during many days during the summer.

TABLE 3
Summary of data for maximum daily water temperature at Headworks, the change in maximum daily water temperature from Headworks to Larson's Bridge, and the calculated starting temperature needed at Headworks to achieve temperature targets at Larson's Bridge

Data Year:	**2000**	**2001**	**2003**
Number of Summer Days Assessed	89	84	97
Headworks Maximum Daily Temperatures During Summer			
--- Minimum Maximum Daily Temperature (°C)	10.1	11.4	12.3
--- Mean Maximum Daily Temperature (°C)	14.3	14.2	15.3
--- Maximum Maximum Daily Temperature (°C)	17.0	16.7	18.2
Change in Maximum Daily Temperatures from Headworks to Larson's Bridge During Summer			
--- Minimum Change in Maximum Daily Temperature (°C)	-1.3	-0.9	-1.0
--- Mean Change in Maximum Daily Temperature (°C)	3.8	3.8	4.2
--- Maximum Change in Maximum Daily Temperature (°C)	9.9	7.9	7.8
Starting Headworks Temperature Needed to Achieve Temperature Target at Larson's Bridge During Summer			
--- Minimum Maximum Daily Temperature (°C)	8.2	9.5	8.7
--- Mean Maximum Daily Temperature (°C)	12.8	12.4	12.9
--- Maximum Maximum Daily Temperature (°C)	16.5	16.6	17.0

Table 4 summarizes the number of days that groundwater augmentation can be used during the summer, and the resultant flows needed to achieve temperature targets at Larson's Bridge (assuming groundwater temperatures of 13°C and 14°C). We use the words "can be used" in the previous sentence because it is evident that groundwater can only be used when groundwater temperature (i.e., of 13°C to 14°C) is less than the estimated "starting" temperatures at Headworks. In this regard, the results in Table 4 indicate that groundwater augmentation can be used on only about 24 to 45 percent of summer days at a groundwater temperature of 13°C, and only about 15 to 27 percent of summer days at a groundwater temperature of 14°C. The calculated starting temperatures at Headworks range from 8.2 to 17.0°C, with a mean of about 12°C to 13°C.

TABLE 4
Summary of data for number of days and flows needed for augmentation to achieve temperature targets at Larson's Bridge if groundwater is assumed equal to 13ºC and 14ºC

Data Year:	**2000**	**2001**	**2003**
Number of Summer Days Assessed	89	84	97
Number of Days and Flows Needed for Augmentation to Achieve Target if Groundwater is Assumed Equal to 13°C			
--- Number of Days When Groundwater Can Be Used	36	20	45
--- Minimum Groundwater Flow (cfs) Needed	3	1	2
--- Mean Groundwater Flow (cfs) Needed	17	15	21
--- Maximum Groundwater Flow (cfs) Needed	34	29	53
Number of Days and Flows Needed for Augmentation to Achieve Target if Groundwater is Assumed Equal to 14°C			
--- Number of Days When Groundwater Can Be Used	27	12	26
--- Minimum Groundwater Flow (cfs) Needed	4	2	2
--- Mean Groundwater Flow (cfs) Needed	19	19	19
--- Maximum Groundwater Flow (cfs) Needed	33	28	50

The results summarized in Table 4 indicate that on days that groundwater augmentation can be used, the groundwater augmentation flows at Headworks needed to meet the temperature target at Larson's Bridge would range from 2 to 50 cfs, with a mean of about 15 to 21 cfs. The variability in the range of groundwater augmentation flows arises from corresponding variability in meteorological conditions and the river's flow levels. For example, the smaller augmentation flow amounts would be needed if unseasonably cool meteorological conditions occur that produce only a modest warming of water from Headworks to Larson's Bridge. On the other hand, the larger augmentation flow amounts would be needed if flows in the river are relatively high (above-average) and very warm meteorological conditions cause a large change in water temperature from Headworks to Larson's Bridge.

Sources and Yields of Groundwater Needed to Meet Temperature Objective

Table 4 indicates that a groundwater-based alternative would require the availability of groundwater flows of 2 to 50 cfs, with a mean of about 15 to 21 cfs, which is equivalent to 9.7 and 13.6 mgd, respectively, or about 48 percent and 68 percent of the estimated achievable yield of 20 mgd for the Headworks area wellfield that the City has considered developing (MSA 2005). However, the system needs to plan for the maximum estimated groundwater flows of 29 to 50 cfs (18.7 and 32.3 mgd, respectively), which is about 94 percent to 162 percent of the achievable yield for the Headworks area wellfield (MSA 2005).

Conclusions

1. The groundwater at Headworks available for release into the lower Bull Run River is too warm to create downstream temperatures that would meet the temperature targets at Larson's Bridge throughout the summer. In general, groundwater discharged to the river must be between about 8°C and 12°C to meet the temperature targets all summer. Specifically, groundwater augmentation can be used on only about 24 to 45 percent of summer days at a groundwater temperature of 13°C, and only about 15 to 27 percent of summer days at a groundwater temperature of 14°C.
2. It is highly unlikely that sustainable pumping rates higher than 20 mgd could be realized in the Headworks area, as would be required during the summer for the groundwater-based alternative, even if more wells were added to the pumping operation.
3. The chemical make-up of the groundwater, while different from Bull Run reservoir water, does not appear to pose water quality issues for aquatic productivity or fish from groundwater discharge to the river.

Final Considerations

The CH2M HILL engineering team brainstormed what options were available for making the use of groundwater a feasible alternative. That is, how could the problems noted above be resolved? Previous studies have pointed out some possibilities and we conceptually developed others, as follows:

- A possible way to overcome the drawdown of the aquifer over time would be to install an ASR system, which would involve pumping water into the aquifer during the winter to replace what had been withdrawn in excess during the previous summer. ASR was analyzed by MSA (2005). MSA (2005) identified ASR as a potential water management strategy for the Headworks wellfield because the Winter Water/Ortley aquifer is confined and the Bull Run watershed produces an abundance of water during the winter months, which could be stored at that time and then pumped for use during the summer. As discussed by MSA (2005), peer reviewers for the preliminary design program concluded that ASR could be beneficial and feasible. However, to meet water quality standards and avoid potential plugging of the aquifer, the ASR water would need to be filtered with a membrane filter prior to injection into the ground. The cost for both systems (ASR and membrane filtration) has not been estimated.
- To resolve the temperature issue the groundwater would need to be refrigerated. There are a number of technological ways to cool water, but the most feasible under the conditions in the Bull Run appears to be centrifugal chillers to cool the water coupled with mechanical draft cooling towers for dissipating condenser water heat (Robinson, 2007). A very preliminary estimate of the cost of this cooling system is about $25 million. To our knowledge, mechanical chilling or cooling for management of river

temperatures with flows between 15 to 21 cfs, and as much as 50 cfs, has never been attempted.

CH2M Hill also identified a number of uncertainties that could affect the feasibility of using Bull Run groundwater to meet water temperature objectives in the lower Bull Run River. These uncertainties are briefly described below.

- Given uncertainties about the chemical compounds (e.g., natural organics) involved in adult fish returning (homing) to the Bull Run River, it is possible that adding groundwater to the river would cause adult fish to become confused when they return to spawn.
- Water rights for groundwater would need to be obtained. The likelihood of obtaining rights for this purpose is unknown.
- Infrastructure of unknown cost would be needed to gather the water from the wells and discharge it properly into the river to avoid erosion and assure proper mixing with water leaving Dam No. 2.
- Table 4 indicates up to 53 cfs of groundwater would be needed at times to achieve temperature objectives at Larson's Bridge. This amount exceeds the capacity of the wellfield envisioned by MSA and described on page 3. It is unclear how the difference between capacity and need would be resolved.
- The HCP also defines river flow objectives to be met at Larson's Bridge, as mentioned on page 8 (measures F-1 and F-2). It is unclear to what degree the amount of groundwater available from the Bull Run wellfield would enable the City to meet the flow objectives.
- Groundwater discharge to the river could have a negative impact on the ability of returning salmon to home to their natal spawning area.

From this brainstorming activity, the engineering team concluded that resolving all these issues would be very costly and that there are many uncertainties about whether some of them could be resolved.

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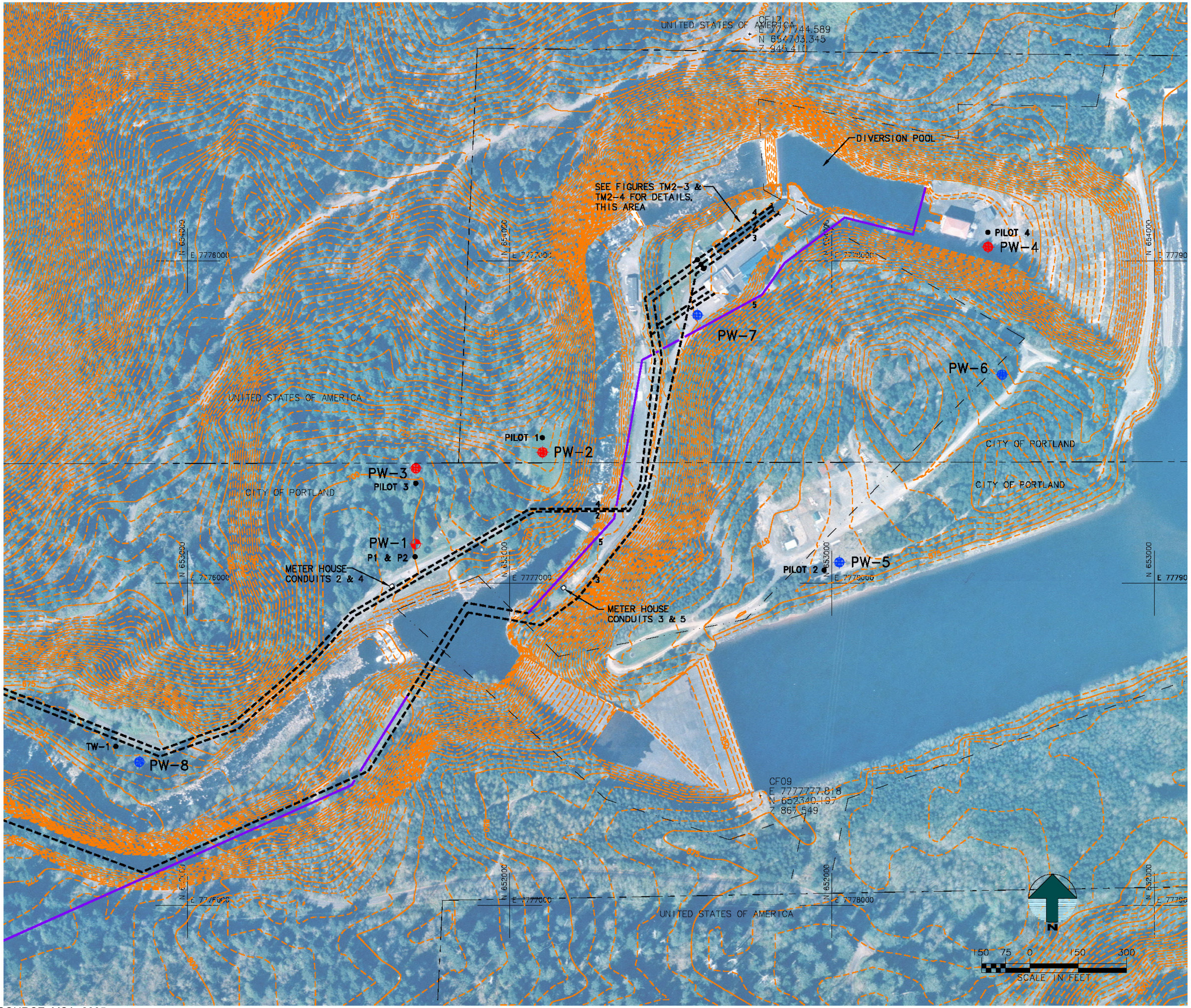

SOURCE: MSA, 2005

LEGEND

	EXISTING	PROPOSED
PRODUCTION WELLS:		
PHASE 1		
PHASE 2		
CONDUITS		
FERC BOUNDARY		

ABBREVIATIONS

PRODUCTION	PW-X
TEST	TW-X
PILOT	PILOT X
PIEZOMETER	PX
WATER SURFACE ELEVATION	WSE

FIGURE 1
WELL LOCATIONS
BULL RUN GROUNDWATER-BASED ALTERNATIVE
TECHNICAL MEMORANDUM

CH2MHILL